Chapter 5

The Architecture of Stream Buffers

Introduction

This chapter emphasizes the importance of protecting key natural areas at the development site. This is done by delineating these areas and protecting them within a buffer system. This chapter provides detailed guidance on how to design and maintain effective buffer systems within a community.

Three primary aquatic areas provide the foundation for the buffer system. They include the *shoreline* of a lake or estuary, a delineated *wetland*, or a *stream* channel. Some of the common delineation criteria for each aquatic area are shown in Table 21.

Additional buffer width can be reserved around aquatic areas to provide further protection. These buffer areas may include sensitive habitats, steep slopes, floodplains and other important resource areas. The width and uses of the buffer zone also depend to some extent on the kind of aquatic area being

TABLE 21. DELINEATION CRITERIA FOR SHORELINE, WETLAND AND STREAM BUFFERS

BUFFER TYPE	SHORELINE BUFFER	STREAM BUFFER	WETLAND BUFFER
Delineation			
Main Objectives:	Separation of land development from aquatic areas, pollutant removal	Preserve stream ecology, prevent flood damage and bank erosion, habitat	Prevent wetland disturbance
Width varies by:	Water use class or designation of lake or estuary	Stream order, and adjacent slopes	Size, type and quality of wetland
Measured from:	Mean high water or high tide line	Bank or stream centerline	Edge of field delineated wetland
Stormwater management	Bypass or treat	Bypass, but some limited treatment	Avoid direct entry
View corridors	Important	Seldom important	Seldom important
Access	Water-dependent	Restricted	Prohibited
Median Width (from Heraty, 93)	75 ft. (lake) 50 ft. (ocean)	88 ft.	100 ft.

Each type of buffer - shoreline, stream and wetland - are different in their design objectives considered for protection (see Table 19).

The remainder of this chapter explores the architecture of a buffer system, with a strong emphasis on how buffers can be applied to protect urban streams. With some subtle refinements, the same basic approach and concepts can also be applied to shorelines and wetland areas.

Some Buffer Geometry and Terminology

To design an effective stream buffer system, it is important to understand spatial connections between the stream and its watershed. A network of streams drain each watershed. Streams can be classified according to their order in that network (Fig. 21). A stream that has no tributaries or branches is defined as a first–order stream. When two first–order streams combine together, a second–order stream is created, and so on. *Headwater streams* are defined as first– and second–order streams. Although they are short in length and drain relatively small areas, these headwater streams comprise of roughly 75% of the total stream and river mileage in the United States (see Table 22).

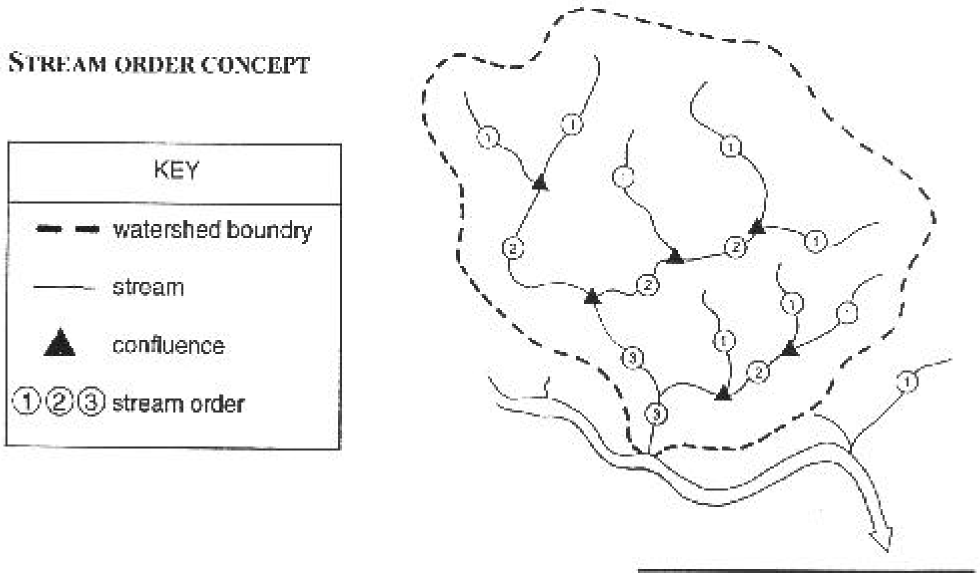
The next key concept is *drainage density* or the length of stream channel per unit area. A region with steep topography, poor cover, and less permeable soils tends to have more stream mileage than a region with less relief and more permeable soils. Geomorphic research has shown that drainage density is remarkably constant within the same physiographic region. Thus, for much of the eastern US, a one–square–mile watershed often has a total stream channel length of 1.4 miles (range 1.0–2.5).

Determining where a first–order stream actually begins in the landscape is not an easy matter. This is due to the complicated path that runoff follows to reach a stream channel. The total distance from the ridgetop (or watershed divide) to the stream channel is known as the *overland flowpath* (Fig. 22). Typically, this distance ranges from 750 to 1,500 feet in many regions of the country. Runoff begins as "*sheet flow*"—the flow is very shallow and spread uniformly over the land surface. Very quickly, however, this uniform flow concentrates to form shallow and then progressively deeper channels, usually within 300 feet of the ridgetop (Ferguson and Debo 1991). These channels only have running water during storm events and are known as *intermittent* channels.

At some point further downstream, groundwater supplies running water to the channel on a year–round basis—these streams are *perennial*. The transition from intermittent channel to perennial stream is not fixed. Indeed, it often moves up or downstream from season to season and year to year, in response to changes in the local water table.

The cross–sectional area of a perennial stream channel fixes that stream's capacity to convey runoff. Typically, an undeveloped stream channel can fully accommodate the peak discharge from a *two–year storm event*, but no more. When the peak discharge rate exceeds the two–year storm event, runoff volume exceeds the capacity of the channel and must

FIGURE 21: STREAM ORDER CONCEPT



Stream order is a useful tool to classify the many elements of the stream network.

TABLE 22: PROPORTION OF NATIONAL STREAM AND RIVER MILEAGE IN HEADWATER STREAMS

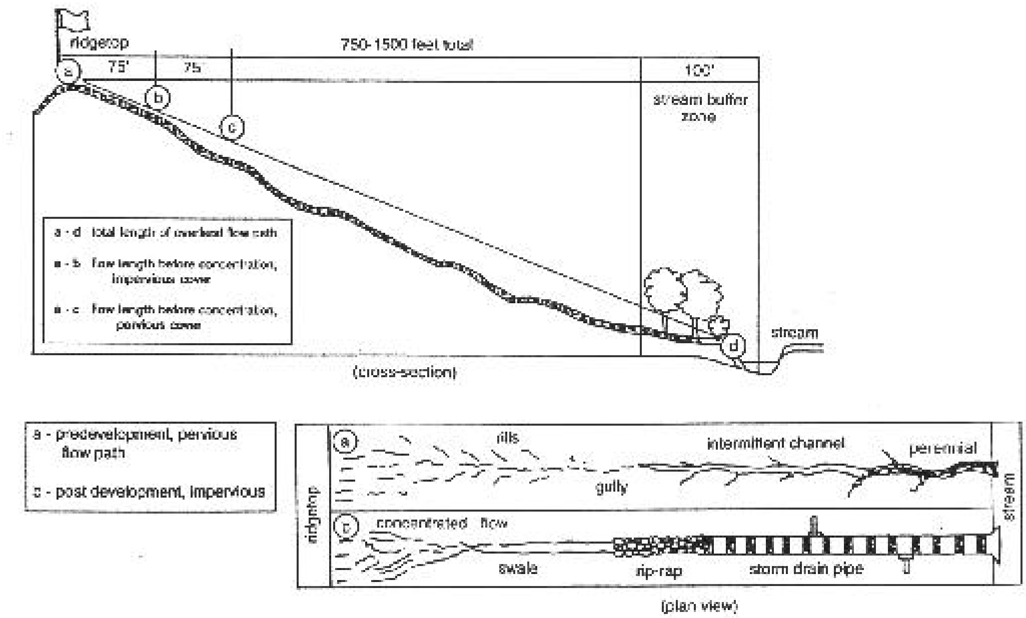
Stream Order*	Number of streams	Total Length of Streams, miles	Mean Drainage Area (sq. miles) **
1	1,570,000	1,570,000	1.0
2	350,000	810,000	4.7
3	80,000	420,000	23
4	18,000	220,000	109
5	4,200	116,000	518
6	950	61,000	2,460
7	200	30,000	11,700
8	41	14,000	55,600
9	8	6,200	264,000
10	1	1,800	1,250,000
Total	2,023,400	3,250,000	N/A

* stream order based on Strahler method, analyzing maps at a scale of 1:24,000.
** cumulative drainage area, including tributaries.

Note: 75% of the total stream and river mileage in the country is in either first or second order streams

FIGURE 22: THE OVERLAND FLOW PATH TO A STREAM

Panel A **Panel B**



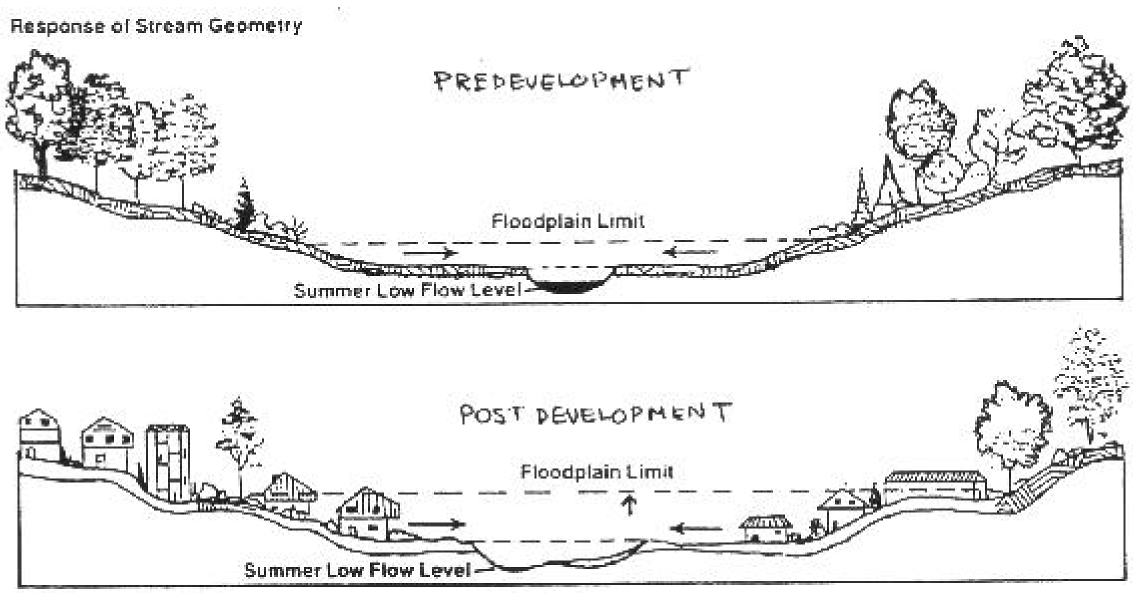
The distance between the ridgetop and the stream is known as the overland flow path. Even in undisturbed watersheds, flow tends to quickly concentrate over a short distance (plan view, panel A). In urban watersheds, flow tends to concentrate even more quickly, requiring stabilization of the intermittent channel (panel B).

spill over the banks into the adjacent *floodplain* on either side of the channel (Fig. 23). By convention, the area and height of the floodplain is defined using the *100–year storm* event. The runoff from this event is determined from the maximum rainfall that has a probability of occurring once every 100 years. The width of the floodplain tends to be narrower in headwater streams and much broader in higher order streams and rivers.

A developed watershed has a remarkably greater rate and volume of runoff for a given storm event than an undeveloped one (cf Chapter 2). As a consequence, both the cross–sectional area of the stream channel and the elevation of the *100–year floodplain* (area immersed during the 100–year flood) are increased. In more practical terms, the stream channel erodes, becoming wider and/or deeper. During extreme floods, a larger land area is subject to flooding after development (see Fig. 23). The severity of the response is a direct function of the amount of *impervious cover* that is created in the watershed.

The geometry of streams and their floodplains is formed by rainfall and runoff. After development, more rainfall is translated into runoff, and the geometry of both the stream and the floodplain changes. A clear understanding of the dynamics of these variables is essential in designing an effective stream buffer scheme.

FIGURE 23: THE STREAM AND ITS FLOODPLAIN, BEFORE AND AFTER DEVELOPMENT



The increase in the peak discharge rates following urbanization shifts the elevation of the 100 year floodplain upward, which may put more property and structures at risk. (Source: Schueler 1987).

Benefits of Forested Stream Buffers

A wide forest buffer is an essential component of any local stream protection strategy. Its primary value is to physically protect the stream channel from future disturbance or encroachment. A network of buffers act as the right–of–way for a stream and functions as an integral part of the stream ecosystem. But a stream buffer also provides many other important benefits that contribute to the quality of the stream and the adjacent community. The many benefits of stream buffers are summarized in Table 23. In many regions, these benefits are amplified when the streamside zone is kept in a forested condition. Recent research indicates that forested stream buffers provide the following benefits:

1. *Reduced watershed imperviousness*

The use of stream buffers can indirectly reduce a site's impervious cover in several ways. To begin with, land within the stream buffer network cannot be developed, and thus will not have impervious cover. How much land does the stream buffer network consume? This question can be answered at the landscape scale by examining the drainage density relationship. In the East Coast, for example, a watershed with a drainage area of one square mile will have a total stream channel length of about 1.4 miles, on average.

TABLE 23: BENEFITS OF URBAN STREAM BENEFITS (f, BENEFIT AMPLIFIED BY OR REQUIRES FOREST COVER)

1. Reduces watershed imperviousness by 5%. An average buffer width of 100 ft protects up to 5% of watershed area from future development.
2. Distances areas of impervious cover from the stream. More room is made available for placement of BMPs and septic system performance is improved.(f)
3. Reduces small drainage problems and complaints. When properties are located too close to a stream, residents are likely to experience and complain about backyard flooding, standing water, and bank erosion. A buffer greatly reduces complaints.
4. Stream "right of way" allows for lateral movement. Most stream channels shift or widen over time; a buffer protects both the stream and nearby properties.
5. Effective flood control. Other, expensive flood controls not necessary if buffer includes the 100-yr floodplain.
6. Protection from streambank erosion. Tree roots consolidate the soils of floodplain and stream banks, reducing the potential for severe bank erosion (f)
7. Increases property values. Homebuyers perceive buffers as attractive amenities to the community. 90% of buffer administrators feel buffers have a neutral or positive impact on property values. (f)
8. Increased pollutant removal. Buffers can provide effective pollutant removal for development located within 150 feet of the buffer boundary, when designed properly.
9. Foundation for present or future greenways. Linear nature of the buffer provides for connected open space, allowing pedestrians and bikes to move more efficiently through a community. (f)
10. Provides food and habitat for wildlife. Leaf litter is the base food source for many stream ecosystems; forests also provides woody debris that creates cover and habitat structure for aquatic insects and fish. (f)
11. Mitigates stream warming. Shading by the forest canopy prevents further stream warming in urban watersheds. (f)
12. Protection of associated wetlands. A wide stream buffer can include riverine and palustrine wetlands that are frequently found near streams.
13. Prevent disturbance to steep slopes. Removing construction activity from these sensitive areas are the best way to prevent severe rates of soil erosion (f)
14. Preserves important terrestrial habitat. Riparian corridors are important transition zones, rich in species. A mile of stream buffer can provide 25-40 acres of habitat areas(f)
15. Corridors for conservation. Unbroken stream buffers provide "highways" for migrations of plant and animal populations.(f)
16. Essential habitat for amphibians. Amphibians require both aquatic and terrestrial habitats and are dependent on riparian environments to complete their life cycle (f)
17. Fewer barriers to fish migration. Chances for migrating fish are improved when stream crossings are prevented or carefully planned.
18. Discourages excessive storm drain enclosures/channel hardening. Prevents increases in runoff from impervious cover and subsequent eroding or overflowing of headwater streams.
19. Provides space for stormwater ponds. When properly placed, structural BMPs within the buffer can be an ideal location to remove pollutants and control flows from urban areas.
20. Allowance for future restoration. Even a modest buffer provides space and access for future stream restoration, bank stabilization, or reforestation.

If a 100–ft wide stream buffer is reserved on each side of the channel, then the buffer would consume about 34 ac or about 5% of the total watershed area. If the zoning density was fixed, this would reduce impervious cover by a like amount. While this represents a modest reduction in total imperviousness at a site, it can be combined with other techniques to achieve a significant watershed reduction.

The second way that stream buffers reduce imperviousness is by forcing a more clustered and compact development pattern. The linear nature of the stream buffer, along with the limitations on roadway crossings, make it nearly impossible to use traditional roadway networks that create needless imperviousness area. (see Chapter 6). Shorter and more economical branching or cul–de–sac road networks are often more feasible residential street designs.

2. Distance from imperviousness to the stream

A stream buffer is also useful in that it increases the distance from impervious areas to the stream. This allows more room to locate effective stormwater BMPs, or to utilize innovative stormwater conveyance systems, such as biofilters. In rural areas, the separation distance helps to improve the performance of on–site septic systems. The greater the distance that subsurface septic system effluent must travel, the greater the chance that soils and plants will remove harmful bacteria and nutrients.

3. Reduce small drainage complaints

Probably the most frequent complaints fielded by local public works agencies concern small residential drainage problems—backyard flooding, streambank erosion, standing water, clogged culverts and the like. The common root of these problems is that property is simply located too close to a stream. By reserving a forested buffer that creates more distance between the residents and the stream, the number of complaints should drop, giving much needed relief to local governments from this time–consuming maintenance burden.

Forest buffers, particularly those with a deep layer of organic matter, can have 10 times more runoff storage capacity and infiltration capacity than a grass or turf area (CBP 1993). This "spongy" quality helps the buffer forests absorb more runoff and should also help reduce drainage problems.

4. Space in which streams can move laterally over time

In a very real sense, a buffer is the right–of–way for a stream, and allows for the physical protection of the stream channel.

Stream channel location is not constant over time. Over the course of decades, the actual position of the channel may wander back and forth across the floodplain (Leopold et al. 1964). Some lateral movement of the stream can and should be expected, even in undeveloped streams.

In urban streams, the lateral movement becomes more rapid and unpredictable. To begin with, most urban stream channels have not yet adjusted to the increased frequency and rate of stormwater runoff generated by upstream development. It is therefore quite common for an urban stream to double or triple channel width before reaching a new equilibrium. Fallen trees from undercut banks can further accelerate the process, resulting in localized widening as much as five times the pre-development channel width.

Clearly, the existence of a wide buffer gives the urban stream the room to move laterally or widen over time, without threatening structures or developed property. When a stream is given room to move, communities often spend fewer dollars for expensive channel protection and stabilization methods that are required to keep a channel in a fixed place.

5. Effective flood insurance

Small stream flooding is a common occurrence in urban areas, even during moderate storm events. Floodwaters can extend far from the channel and damage property and structures. However, when the post-development 100–year floodplain is wholly contained within a stream buffer, the risks of flood damage are greatly reduced. Because structures are kept away from the floodplain, they do not need to be “floodproofed” with expensive protective measures. Thus a stream buffer is an effective form of flood insurance for a community and conforms with federal flood insurance requirements (FEMA).

In addition, the dedication of a buffer provides for temporary storage of floodwaters in headwater streams (for extreme floods greater than the two year event), thereby reducing the height of the flood crest for downstream areas (Karr and Schlosser 1978).

6. Protection against streambank erosion

A deep network of tree roots consolidate the soils of the floodplain, making them more resistant to erosive forces of runoff. The shallow roots of grass, on the other hand, provide little resistance to bank erosion (Karr and Schlosser 1978). When deep tree roots are absent, the toe of the streambank is very susceptible to rapid erosion. The bank then begins to undercut, and blocks of turf at the top of the bank begin to slump into the channel (Sweeney 1993). These eroded sediments are deposited in the channel, where they can smother the existing stream substrate. Also, deposited sediments temporarily reduce the cross–sectional area of the channel, thus leading to a new and more severe phase of bank erosion.

7. Increased property values

Forested buffers create a more natural and attractive sense of community. A national survey of 36 stream buffer program administrators indicated that stream buffers were perceived to have either a neutral or positive impact on adjacent property values (Heraty 1993). None of the respondents indicated that buffers had a negative impact on land value.

This finding is consistent with numerous other studies that have found that greenways and buffers increase property values of adjacent homes (Correl et al. 1978, Seattle Office of Planning (1987) and Mazour (1988).

8. Increased pollutant removal

Urban stream buffers have the potential to remove pollutants that move through them, in groundwater or sheet flow. Soils and vegetation within the buffer act as a living filter. Pollutants in stormwater settle out, adsorb to soil, or are taken up by vegetation. Performance monitoring studies suggest that stream buffers can remove the majority of sediment and trace metals that are delivered to them, as long as even and uniform sheet flow is maintained across the outer edge of the buffer. Removal of phosphorus and nitrogen appears to be modest, and more unreliable (see Table 28).

It is important to note that stream buffers cannot be relied on as the sole urban BMP at most development sites. Most of the runoff produced in urban areas concentrates too quickly to be effectively treated by a buffer, and other, more structural, BMPs must still be installed (e.g., stormwater ponds, wetland infiltration or filtering system).

9. A foundation for greenways

At the landscape scale, a buffer network provides a connected system of open space that can link a community together. A buffer serves as the foundation of a greenway that can meet the recreational needs of adjacent urban residents. The greenway can contain foot trails, which allow for easier pedestrian movement through the community or to provide an opportunity for nature enjoyment. Surveys by Adams (1994) indicate that 58% of suburban residents actively engage in wildlife watching and nature enjoyment near their homes. Residents also exhibit a keen desire to live next to natural areas and are willing to pay a premium for homes located next to them (Adams et al. 1983)

Where the stream buffer is wide enough and publicly owned, it can also serve as the site of a bikeway that links the community together. Because bikepaths are impervious and require clearing of vegetation, they should be carefully located in the outer zone of a buffer.

10. Provision of food, cover, and stream habitat

Riparian forests are an integral part of the stream ecosystem. Trees supply the stream with leaf litter, which constitutes the major source of energy in headwater streams in most parts of the country. Leaf litter and woody debris literally form the base of the food chain. Bacteria and fungi colonize these packs of organic matter and are in turn consumed by aquatic insects, which are eaten by other insects and fish. Thus the annual leaf fall supplied from a forested buffer is the key energy source for every trophic level in the stream.

The adjacent forests also supply large woody debris to the stream channel. These logs, branches and twigs create more structural complexity within the channel and thus more habitat area for aquatic insects. The woody material often forms natural debris dams that help a headwater stream retain more of its nutrients and organic matter. For example, Sweeney (1993) noted that forested streams had 17 times as much wetted benthic habitat area as unforested streams. In addition, forested streams had eight times as much woody debris and 38 times as much leaf litter as unforested streams. The presence of a forest buffer also appears to directly influence the quality and the diversity of the stream community. Both Steedman (1988) and Sweeney (1993) have extensively documented that a stream insect community declines in total area and diversity when the forest cover is lost.

11. Stream warming is mitigated

Mature forests provide shade that keeps stream temperatures from rising during the summer months. When the forest cover is removed, an urban stream will invariably heat up by as much as 5–10 degrees F (Greene 1950, Pluhowski 1970, Sweeney 1993, and Galli 1991). A temperature increase of this magnitude can seriously threaten the survival of trout and other salmonid fish species, as well, as well as some sensitive aquatic insects, such as stoneflies.

12. Wetland protection

Wetlands often are the surface expression of

the underlying water table. Some type of wetland is almost always found where the water table is at or near the surface. Likewise, perennial streams are also an expression of the water table where it meets the lowest point in the local landscape. As such, streams are almost always associated with certain types of riverine and palustrine wetlands. Located near the stream channel or in the adjacent floodplain, these wetlands are often forested and of high functional quality. Clearly, by reserving a wide stream buffer, it is possible to more systematically protect these important wetlands from disturbance. In addition, extending the buffer network beyond the limits of a wetland provides a more effective transition zone between the wetland and upland urban areas.

13. Prevention of soil erosion from steep slopes

Steep slopes and streams are often located near each other, as the stream has historically been the erosional agent that creates sharp relief. Steep slopes pose the greatest risk of sediment delivery during construction. The combination of steepness and proximity to the stream make these slopes the most susceptible areas for erosion at any development site. Sediment loads from these areas can be exceptionally high, even when the best erosion and sediment control techniques are applied. Where stream buffers are expanded to fully include all adjacent steep slopes and thereby prevent their clearing and disturbance, they can be a very effective component of an erosion and sediment control plan.

14. Preservation of wildlife habitat

A continuous one–mile stream buffer that extends 100 ft outward on either side of the channel preserves about 25 ac of contiguous stream or riverine habitat. A stream buffer acts as a habitat “island,” a transition zone between aquatic and terrestrial environments. Most ecologists have concluded that the total number of species of birds, mammals, reptiles, and amphibians, is strongly related to the area of a habitat island—as it gets larger, more species are recorded.

Studies of wildlife diversity in urban habitat islands suggest that a surprising number of bird, mammal and reptile species can be found in contiguous habitat island that are 25 ac or greater in area (Table 24).

15. Creation of wildlife corridors

In addition to their intrinsic value as wildlife habitat, stream buffers also create potential corridors for wildlife travel between larger habitat islands in the urban landscape (e.g., urban forest preserves, natural wetland complexes, stormwater wetlands and community parks). Not only do stream buffers increase the effective size of the total habitat island, but they provide source populations of organisms for future recolonization. To be most effective, a wildlife corridor should be 300–600 ft wide (Desbonnet et al. 1994).

16. Critical amphibian habitat

Amphibians have a terrestrial and aquatic life cycle and require both habitats in close

TABLE 24: URBAN WILDLIFE SPECIES DIVERSITY AS A FUNCTION OF HABITAT ISLAND SIZE

Habitat Island Size	5 acre	10 acre	20 acre	30 acre	40 acre	50 acre	75 acre	100 acre
Woodland Birds*	--	13	21	27	29	31	33	34
Woodland Birds*	24	27	31	33	36	37	40	43
Woodland Birds*	14	21	29	33	36	38	43	46
Chaparral Birds	2.5	3.4	4.3	4.8	5.2	5.5	6.0	6.4
Land Vertebrates	14	21	33	42	51	59	76	95
Beetles	--	6.6	7.7	8.5	9.0	9.5	10.4	11.2
* Studies from three different eco-regions around the world								

As Adams (1994) data illustrates, the number of bird, mammal and insect species increases as the area of the "habitat island" increases proximity. Thus amphibian species are commonly found in greatest abundance within the stream buffer zone. Tree frogs, salamanders, spring peepers, and other species create the diverse musical chorus heard in the spring and summer riverine woods. Amphibians appear to be undergoing a world–wide decline in abundance, particularly in urban and suburban areas (Minton 1968, Cochran 1989). A number of researchers have noted the importance of stream buffers to support amphibian populations in urban areas.

17. Barriers to fish migration are discouraged

Stream buffer programs regulate the manner in which the stream channel is crossed by highways, utilities, and other linear development. When utilized properly, a stream buffer regulation can prevent the creation of unintentional barriers to upstream fish migration, such as roadway culverts, grade control structures, hardened utility crossings and the like.

18. Excessive storm drain enclosures/channel hardening avoided

Headwater streams are exceptionally vulnerable to physical elimination in urban watersheds. Once impervious cover in the watershed exceeds 30 to 60%, stormwater flow becomes so great that many natural channels cannot withstand them without severely eroding or overflowing (cf Chapter 2). As a consequence, many open channels and headwater streams are enclosed in storm drains to more quickly route stormwater runoff off the site and prevent temporary flooding of streets and parking lots.

The loss of headwater streams can be striking. In some highly developed urban areas, the majority of headwater streams have been enclosed by storm drains or hardened channels. While a stream buffer may not fully protect an urban stream channel from erosion (upstream BMPs are still needed), it may reduce the need for costly bank and channel protection techniques.

19. Good sites provided for stormwater ponds

A buffer system provides an excellent framework within which stormwater BMPs can be integrated. It is the most effective and economical place in the landscape to provide stormwater quantity and quality control. When carefully located and designed, these ponds can maintain the quality of the stream and the buffer network.

20. Allowance for future restoration

Stream buffers are a prerequisite for future watershed restoration. Most urban watershed restorationists have discovered that the best locations and opportunities for restoration projects are along the stream buffer. This relatively narrow strip of land provides numerous sites for riparian reforestation, access for stream restoration projects, and many candidate locations for stormwater retrofit projects. At its most fundamental level, the reservation of a stream buffer enables a community to fix in the future some of the mistakes it may have made in the past. Without a pre–existing stream buffer, such restoration is seldom possible.

Local Experience with Buffer Programs

Communities have learned that they must go beyond merely drawing a line on a map during the development review process. They must also actively manage and protect a stream both during the construction process and over time in the changing landscape.

Our most detailed knowledge about the quality of local buffer programs comes from a detailed national survey of 36 local and state programs by Heraty (1993) The responses from planners and engineers suggest that most local buffer programs could stand significant improvement in how they are administered. Indeed, respondents in nearly 25% of all programs surveyed have already recognized this need and have revisited their buffer programs to improve their effectiveness. The survey results are supplied in Appendix B, and some of the key findings are provided below:

1. Buffer boundaries are largely invisible to local governments, contractors and residents.

Stream buffer boundaries may be drawn on development plans, but they often become invisible after the plans are approved. The survey indicated that over two–thirds of all communities that required buffers did not record their presence on their official maps. Without buffer maps, local governments cannot systematically inspect or manage their network of buffers. In addition, less than half of all communities required that the buffer boundaries be shown on construction plans, such as clearing and grading plans or erosion and sediment control plans. The absence of buffer limits on construction stage plans increase the risk that contractors will encroach upon or disturb the buffer during the construction phase.

The survey also revealed that 60% of property owners were largely unaware of the boundary or purpose of the stream buffer in their community. This ignorance could generally be traced to the lack of active notification by local governments about the boundaries of buffers to new property owners.

2. Buffers are subject to extensive encroachment in urban areas.

When boundaries are not well defined, buffers become an urban "commons" area, subject to encroachment pressures from adjacent property owners and other users. The pressures begin during the construction stage, where a buffer may be subject to illegal clearing and grading, compaction of soils, tree damage from heavy equipment, and sediment impacts due to poor erosion controls elsewhere on the site. Corish (1995) notes that over 50% of communities surveyed reported that site clearing and grading operations frequently do not protect preserve vegetated areas, and that 25% of all buffers are materially damaged during construction. Corish's finding is comparable to Heraty's, indicating that 26% of jurisdiction report frequent buffer encroachment during construction.

Encroachment pressures continue well after the site has been developed. Some indication of the extent of these pressures can be gleaned from Cooke's 1991 study of 21 urban wetland buffers in the State of Washington (Table 25).

TABLE 25: ENCROACHMENT PRESSURES ON URBAN WETLAND BUFFERS IN WASHINGTON (COOKE 91)

Category of Disturbance	% of Buffers Disturbed
Dumping of Yard Wastes	76
Conversion of Natural Vegetation into Lawn or Turf	100
Tree Removal	50
Evidence of Fertilizer Impact	55
Evidence of Stormwater Short-Circuiting Buffer	28
Increased Dominance of Invasive/Exotic Plants	67
Evidence that Buffer had been Maintained	5
Trails Established in Buffer	29
Buffers Exhibiting Signs of Alteration	95
Severely Altered Buffers (Not Protecting Adjacent Wetland)	43

The buffers ranged in age from two to eight years. Ninety–five percent of the buffers showed visible signs of encroachment or disturbance, including mowing, dumping of yard wastes, tree removal, trails, and erosion. Those buffers located next to residential areas were often cleared of native vegetation and replaced with lawns (often with high fertilizer input).

3. Few jurisdictions have effective buffer education programs

The lack of awareness about stream buffers is not surprising since only 15% of all programs marked or posted buffer boundaries. Usually the only notification given about the existence of buffers was a one–time legal disclosure, such as recordation on the property deed, language in a homeowner association charter, or a written disclosure upon resale. Surprisingly, 47% of all buffer programs had no specific notification program for individual property owners at all.

Increasingly, communities are experimenting with new and innovative techniques to educate their residents about buffers, including pamphlets, boundary markers, buffer walks, regular homeowner's association meetings, and individual maintenance agreements. One promising approach involves enlisting residents to plant native trees and shrubs in their backyards to attract wildlife and save water. This "bufferscaping" effort not only increases the width of the buffer, but actively involves interested residents in the stewardship of the buffer and the stream environment.

4. Allowable and unallowable uses are seldom defined

In addition to the inexorable pressure from adjacent land owners, a buffer planner must reconcile what uses are to be allowed or denied within the buffer zone. Potential uses are bike trails, footpaths, BMPs, utility crossings, campgrounds, athletic fields, playgrounds, gazebos, decks, streambank stabilization projects, parallel pipe systems, and many others (Table 26).

TABLE 26: ALLOWABLE AND UNALLOWABLE USES IN THE STREAM BUFFER ZONE (SOURCE: HERATY 1993)

Use	*Allowed*	*Denied*
Footpaths	60	8
Utility line crossings	52	5
Water dependent uses	45	10
Bike paths	30	15
Stormwater BMPs	28	10
Home additions/decks/gazebos	10	55
Maintenance for flood control	Often Allowed	
Pumphouses	Restricted	
Sewage treatment plants	Restricted	
Golf Courses	Restricted	
Campground	Restricted	
Timber Harvesting	Restricted	
Hydropower	Restricted	
Roads/Bridges	Restricted	
Athletic Fields	Restricted	
Playground Equipment	Restricted	
Compost/Yard Wasted	Unrestricted	
Landscaping	Unrestricted	
No Uses Permitted (30%)		
No Uses Denied (15%)		

Percentages of buffer programs that specifically allow or deny a given use. The "Restricted" and "Unrestricted" entries refer to other stream buffer uses that are not commonly addressed in local ordinances.

Many communities have revisited their stream buffer ordinance to make better decisions on the use of the buffer. In general, uses that create impervious surfaces, require extensive clearing, generate pollutants, or that can be located elsewhere are not allowed (MWCOG 1995). Uses that create minimal or temporary changes to the buffer, such as foot paths or stormwater BMPs, or that cannot be located away from the stream (utility crossings, water–dependent access) are generally allowed.

5. Few jurisdictions specified mature forest as a vegetative target

Few jurisdictions clearly specify a vegetative goal of mature forest for their stream buffer program. Heraty (1993) found that over two–thirds of all programs simply required that pre-development vegetative cover be maintained, regardless of whether it was trees, weeds, or turf. Indeed, 20% of all buffer programs failed to specify any vegetative goal at all. Given the importance of riparian forests in the ecology of headwater streams, the adoption of a specific vegetative target for the stream buffer would be wise.

6. Accuracy of buffer delineation seldom confirmed in the field

Local programs encounter a number of difficulties in accurately delineating buffer boundaries at individual development sites. For example, Heraty (1993) reported that nearly 50% of the buffer programs find that buffer widths are not measured from an appropriate baseline, or that consultants do not properly expand the buffer width to pick up floodplains, wetlands or critical habitats specified in their ordinance. One–third of the governments indicate that consultants fail to draw buffer boundaries on site plans or construction drawings, even when this has been mandated. Some 30% of all respondents indicated that they did not have the time or resources to check the validity of the developer's buffer delineation on the plans at all. It is speculated that an even greater number failed to confirm stream and buffer boundaries in the field.

Twenty percent of jurisdictions had no mechanism to inform the contractor about buffer boundaries during construction. On the positive side, Corish (1995) reported that 75% of respondents did inspect the condition of the buffer at least once after construction had begun. In general, local governments consistently noted problems during the construction stage. For example, respondents reported that erosion control structures were not properly maintained (67%), cleared areas were poorly revegetated (56%), cleared slopes were not adequately stabilized (44%), cleared land was exposed for longer than the prescribed maximum time period (44%) and that soils were heavily compacted (28%). Indeed, only a mere 18% of all jurisdictions surveys concluded that "few problems were encountered in implementation" (Corish 1995).

7. Most buffers remain in private ownership

The vast majority of buffers (90%) remain in private ownership after development (Heraty 1993). Access and use is solely restricted to the property owner. In some subdivisions, the buffer is considered semi–private open space and is dedicated to a homeowner association, which manages the buffer and can control or restrict access. Only 10% of all communities require that the buffer be public open space, and dedicated to the local parks authority. In privately owned buffers, use restrictions are primarily spelled out in the property deed of record. A formal conservation easement is utilized in only about 11% of cases.

Residents appear to broadly support privately owned stream buffer programs in their community. Over 80% of local governments agreed with the statement "that a majority of our citizens think that the community is better off having stream buffers," and that the stream buffers had a neutral (54%) or positive (40%) influence on adjacent land values.

This is not to imply that buffers are popular with all residents. A sampling of the most frequently cited complaints about buffers from residents include:

- the buffer system gives strangers access to my backyard
- the buffer is a breach of my property rights
- access along the stream buffer is denied
- vagrants and teenagers use the buffer for illegal purposes
- trees obstruct water or scenic views
- I am taxed on land that I cannot develop
- buffers are a source of varmints, weeds, ticks, feral dogs, etc.
- the process for adding decks, sheds, gazebos is too restrictive
- the buffer is in an unsightly condition during early stages of forest growth
- unfair to those who owned land prior to the buffer law

By and large, resident complaints about stream buffers are uncommon and can be directly addressed through a concerted education program to inform residents of the many benefits buffers provide, as well as clear enforcement of trespassing laws. Interestingly, many communities often receive an equal number of complaints from residents that demand better stewardship of the buffer system.

8. The stream buffer program needs to be responsive to the interests of the development community

Although the stream buffer system is not likely to consume more than 5% of the land area of a watershed (much of which cannot be developed anyway because it is also a floodplain, wetland, or steep slope), it can consume a much larger proportion of an individual development site. Clearly, the potential exists to generate complaints about excessive regulation and property right issues. While only one community reported developer complaints that stream buffers actually stifled development activity (Heraty 1993), the development community does express strong concerns in several areas:

- inflexible buffer delineation
- inconsistent application of buffer guidelines
- lengthy approval process
- lost lots that could have been developed
- extra costs for development submittal
- buffer use are too restrictive (e.g., stormwater BMPS are not allowed)

While the philosophical issue of property rights infringement can never be satisfactorily resolved for all developers, local governments are encouraged to craft their programs to be responsive to the economic needs of the development community. After all, the primary purpose of the stream buffer program is to place some distance between development and the stream—and not to discourage development from taking place.

Pollutant Removal Capability of Stream Buffers

While an urban stream buffer provides many impressive benefits, it must be emphasized that they often have a limited capability to remove pollutants borne in urban stormwater runoff. This is a surprising conclusion for a number of reasons. First, many communities have cited pollutant removal as the key justification for establishing buffer programs (Heraty 1993). Second, high removal rates have been frequently reported for forested buffers in rural areas (Desbonnet et al. 1994). Why, then, do stream buffers have limited value to remove pollutants in stormwater runoff?

The primary reason relates to how flow reaches the stream buffer in urban watersheds. Buffers require the presence of sheet flow to be effective. Once flow concentrates to form a channel, it effectively short–circuits the buffer and no treatment occurs. Unfortunately, flow usually concentrates within a short distance in urban areas. It is doubtful, for example, whether sheetflow conditions can be maintained over a distance of:

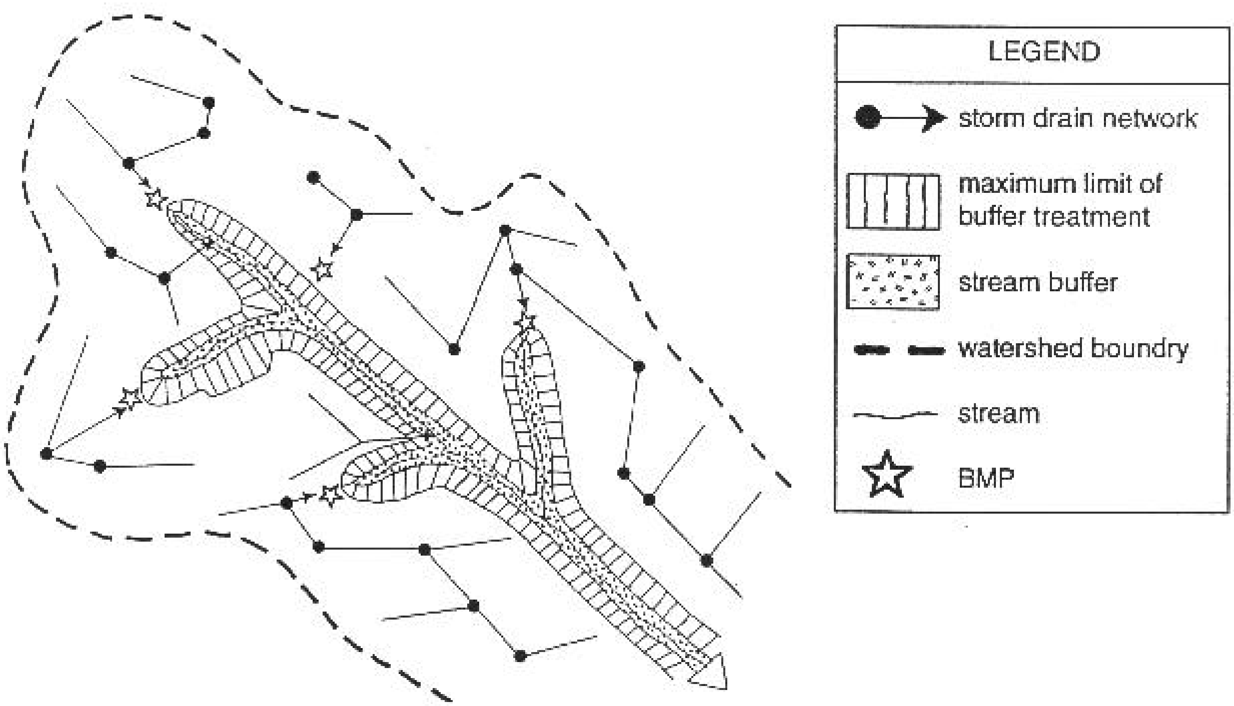
- 150 ft for pervious areas
- 75 ft for impervious areas

This constraint sharply reduces the percentage of a watershed that can be effectively treated by a stream buffer. This can be illustrated using the drainage density example that was used earlier. If we assume that (a) 1.4 miles of stream exist in a one square mile watershed, (b) a 100–ft buffer exists on each side of the channel and (c) that each side of the buffer serves the maximum limit of 150 ft of contributing pervious area, we would be able to directly treat about 50 ac total of pervious area. This acreage represents only 8% of the total drainage area to the stream (or 13% if we include the area in the stream buffer) This implies that the runoff from the remaining 87% of the total drainage area will be delivered to the stream in one of three ways:

- in an open channel
- within an enclosed stormdrain pipe, or
- a stabilized outfall channel from a BMP

In each case, the channel or pipe will cross the stream buffer before it discharges into the steam (Fig. 24) In addition, some kind of structural BMP will still be needed to provide water quality control for the runoff before it reaches the stream.

FIGURE 24: THE ENTRY OF STORMWATER RUNOFF INTO THE URBAN STREAM BUFFER NETWORK



Due to the rapid concentration of flow, most runoff enters the buffer in an open channel or stormdrain pipe. On a watershed scale, a buffer only receives 10% of the sheetflow.

The four basic options for providing stormwater quality control include:

- stormwater ponds
- shallow wetlands
- infiltration practices
- filtering systems

Each practice must be fully integrated within the stream buffer system in order to maximize treatment efficiency and ensure that the largest possible contributing drainage area is captured.

Urban Vegetative Treatment Systems

Under some circumstances, an urban stream buffer can be employed as a vegetative filter to treat the quality of stormwater runoff. Indeed, a wide variety of vegetative filters have been used for this purpose. While each of these filters relies on the use of vegetation to slow runoff velocity and filter out pollutants, not all of them are comparable. Consequently, their design and pollutant removal performance are often quite different. The differences are often amplified by the diverse and conflicting terminology used to describe urban vegetative filter systems (Table 27).

TABLE 27: SOME STANDARDIZATION OF URBAN VEGETATIVE FILTERING SYSTEMS

FILTER	Open Channel Systems	Filter Strip Systems	Buffer Systems
FLOW	shallow flow occurs through a designed open channel, concentrated outflow	grass filter that accepts sheetflow from adjacent areas, no concentrated outflow	primarily used to protect stream, but can act as a filter under restricted conditions
TERMS	swale (wet or dry) grass channel grass swale bioswale biofilter bioretention swale	filter strip vegetated filter strip grass filter strip grass buffer bioretention area	forest buffer stream buffer riparian filter buffer strip urban buffer treatment

For example, as many as 15 different names have been given to these practices, and these are often used interchangeably. In reality, however, most vegetative filters can be grouped in one of three general categories:

Open Channels: designed to filter out pollutants in stormwater as they are conveyed through an open, grassy channel. Sometimes known as swales, the channel conveys stormwater runoff across the stream buffer and discharges directly into the stream. From a pollutant removal standpoint, there are four basic design options for the open channel, which are described in detail in Chapter 6 (Page 157).

Filter strips: designed as a grass filter that accepts sheetflow from impervious or pervious areas to pretreat it before it is delivered to a stream buffer or downstream BMP. As noted before, urban filter strips can treat runoff over a relatively short distance (usually 75 to 150 feet). Some design guidance for urban filter strips can be found on page 116.

Forested buffers: primarily designed to protect streams; forest areas may provide some treatment of stormwater runoff from nearby pervious or impervious areas but this is only a secondary benefit. In most cases, stormwater runoff from upland areas crosses the forested stream buffer in the form of an open channel or an enclosed storm drain. The pollutant removal benefit of stream buffers can be more significant in low-relief coastal areas, where groundwater interaction is strong.

Performance of urban vegetative practices: Our current knowledge about the pollutant removal capability of each of the three categories of urban vegetative practices is summarized in Table 28, and is described below:

Open Channels: the performance of grassed open channels has been reasonably well studied in a wide number of environments around the country. The studies indicate that grassed channels have a high capability to reduce sediment, hydrocarbon and metals in most situations (>50%). However, their ability to remove phosphorus and nitrogen is much more limited and unreliable, with removal rates averaging only 10 to 50%. Grassed channels have shown little capability to reduce bacteria, chlorides or nitrate, with zero or negative removal rates frequently reported.

Filter strips: only one study has assessed the capability of a grass filter strip to treat urban stormwater runoff. Yu et al. (1992) reported moderate to high removal rates for a 150–ft strip that treated runoff from a large parking lot, but mediocre performance in a shorter, 75–ft strip.

Stream buffers: at the present time, there is no performance data on the effectiveness of forest stream buffers to treat urban stormwater runoff. Some indication of their potential effectiveness can be inferred from the performance of forest and grass buffers from agricultural areas.

TABLE 28: MEASURED POLLUTANT REMOVAL CAPABILITY OF SELECTED URBAN VEGETATED FILTERS

BMP System	TSS	TP	TN	Zinc	Lead
Grass Channel (1)	83	29	(neg) *	63	67
Grass Channel (2)	81	17	40	69	50
Grass Channel (2)	87	83	84	90	90
Grass Channel (3)	65	41	>20.	49	47
Grass Channel (3)	98	18	>50	81	81
Grass Channel (4)	72	54	ND	74	ND
Filter Strip-75' (5)	54	(-25)	(-27)*	47	(-16)
Filter Strip- 150'(5)	84	40	(-20)*	55	50
MEAN NON URBAN (6)	73	56	63	--	--
MEAN URBAN	78	32	25	66	53

***nitrate-N only**

REFERENCES

(1) Seattle METRO 1992 (2) Harper 1988 (3) Dorman et al. 1989
(4) Yu et al. 1993 (5) Yu et al. 1992 (6) Desbonette et al. 1994

While grass channels generally are reported to have a high capability to remove sediment, their ability to remove nutrients varies substantially, often due to soil, slope and other factors.

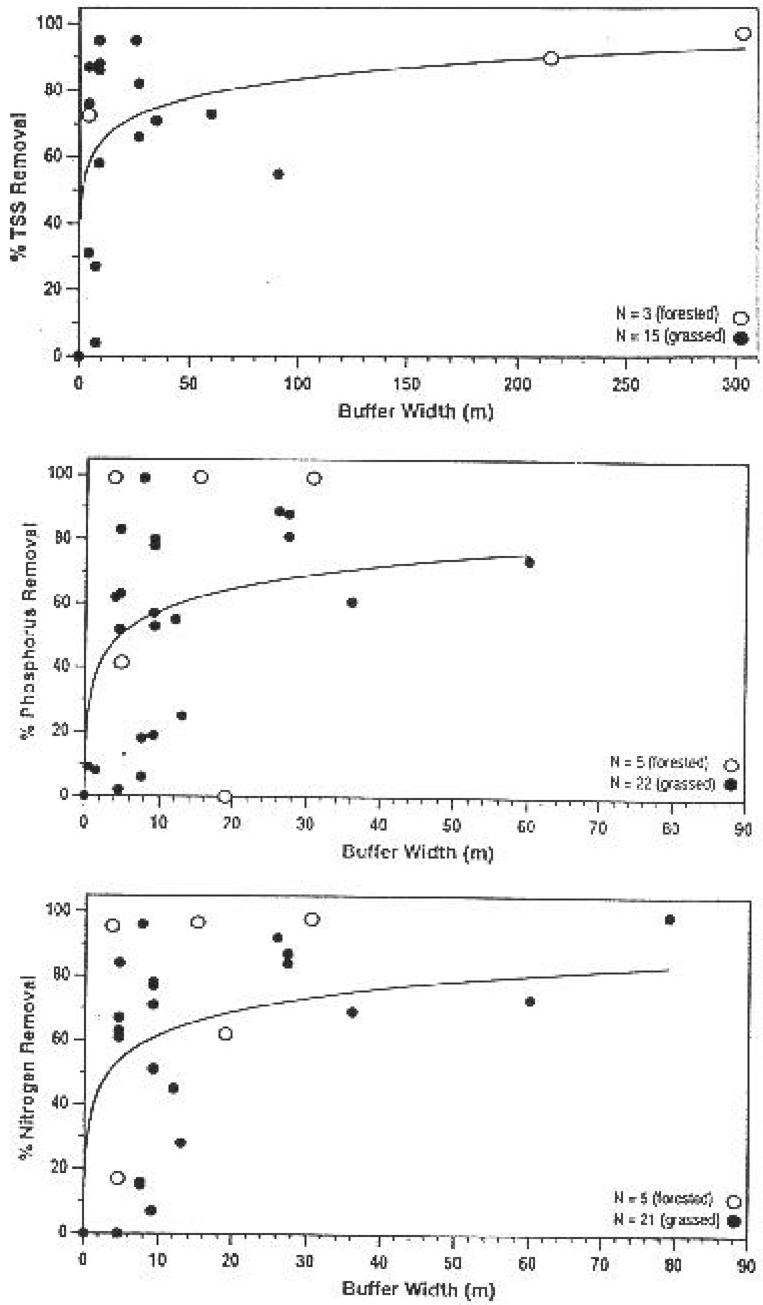
The moderate to high pollutant removal observed in rural and agricultural buffers appears to be due to the relatively slow transport of pollutants across the buffer in sheet flow or shallow groundwater flow. In either case, the relatively slow movement of water gives soil, roots and microbes more time to trap or remove pollutants. Desbonnet et al. (1994) recently reviewed over 35 monitoring studies that investigated the pollutant removal performance of rural and agricultural buffers (Fig. 25).

FIGURE 25: SURFACE POLLUTANT REMOVAL IN AGRICULTURAL FILTER STRIPS

PANEL A
TOTAL SUSPENDED SOLIDS REMOVAL

PANEL B
TOTAL PHOSPOROUS REMOVAL

PANEL C
TOTAL NITROGEN REMOVAL



Desbonnet et al. (1994) compares the reported removal efficiency of 35 buffer strips, most of which were located in rural or coastal areas. The effect of buffer width on sediment, phosphorus and nitrogen removal are shown in panels a - c.

Although considerable variation was observed among the studies, several performance trends emerged:

- Buffers were generally capable of removing 75% of the suspended sediment delivered to them in surface runoff, even when the grass buffer was as narrow as 25 ft.
- Removal of nitrogen and phosphorus in surface runoff seldom exceeded 50 or 60%, even in widest buffers monitored. Further increases in nutrient removal required that buffers extend 300 to 600 ft long, a rather impractical length.
- Removal of nutrients in subsurface or groundwater flow was very inconsistent. Under ideal site conditions—poorly drained and organic rich soils, deep root systems and groundwater flow within two to six feet of the surface—buffers exhibited exceptional removal of nitrate– nitrogen—often 90% or more. When such conditions exist, buffers can be very useful in reducing the nitrogen effluent from rural septic systems.

In general, most researchers consider agricultural buffers to be a useful BMP, but only when they are combined with other practices (Magette et al. 1989). It is also widely recognized that many agricultural buffers fail to perform as designed after they are installed in the field (Dillaha et al. 1989). Field surveys indicate that many agricultural buffers lack good vegetative cover, are subject to excessive sediment deposition, or are short–circuited by channels formed by concentrated flow.

***Summary**: Potential Pollutant Removal Capability of Urban Stream Buffers.*

On the basis of performance data from related vegetative systems, it is possible to estimate the pollutant removal capability of an urban stream buffer (i.e., explicitly designed to treat stormwater using the design procedure outlined in Buffer Criteria 7). The hybrid of the grass strip in the outer zone and the forested buffer in the middle and streamside zone has the *potential* to achieve the following removal rates:

Sediment	75%
Total Nitrogen	40%
Total Phosphorus	50%
Trace Metals	60 to 70%
Hydrocarbons	75%

The ability of a particular buffer to actually *achieve* these rates depends on many site–specific factors that are outlined in Jordan (1995). The design procedure outlined in Criteria 7 is intended to restrict the use of the stream buffers for stormwater treatment only to those conditions where site–specific factors assure reliable pollutant removal (Table 29).

Performance Criteria for Urban Stream Buffers

The ability of a particular buffer to realize its many benefits depends to a large degree on how well it is planned, designed, and maintained. Ten practical performance criteria are offered to govern how a buffer is sized, managed, and crossed and how it is to

TABLE 29: SITE FACTORS THAT ENHANCE OR DETRACT FROM POLLUTANT REMOVAL PERFORMANCE IN URBAN VEGETATIVE FILTERING SYSTEMS

Factors that enhance performance	**Factors that reduce performance**
Slopes less than 5%	Slopes greater than 5%
Contributing flow lengths < 150 ft.	Overland flow paths over 300 feet
Water table close to surface	Groundwater far below surface
Check dams/level spreaders	Contact times less than 5 minutes
Permeable, but not sandy soils	Compacted soils
Growing season	Non–growing season
Long length of buffer or swale	Buffers less than 10 feet
Organic matter, humus or mulch layer	Snowmelt conditions, ice cover
Small runoff events	Runoff events > 2 year event
Entry runoff velocity less than 1.5 fps	Entry runoff velocity more than 5 fps
Swales that are routinely mowed	Sediment buildup at top of swale
Poorly–drained soils, deep roots	Trees with shallow root systems
Dense grass cover, six inches tall	Tall grass, sparse vegetative cover

handle stormwater. The key criteria include:

1. Minimum total buffer width
2. Three–zone buffer system
3. Mature forest as a vegetative target
4. Conditions for buffer expansion or contraction
5. Physical delineation requirements
6. Conditions where the buffer can be crossed
7. Integrating stormwater and BMPs within the buffer
8. Buffer limit review
9. Buffer education, inspection, and enforcement
10. Buffer flexibility

Criteria 1. Minimum total buffer width.

Most local buffer criteria consist of a single requirement–that the buffer be a fixed and uniform width from the stream channel. Urban stream buffers range from 20 to 200 ft in width on each side of the stream according to a national survey of 36 local buffer programs, with a median of 100 ft (Heraty 1993). Most jurisdictions arrived at their buffer width requirement by borrowing other state and local criteria, local experience, and, finally, through political compromise during the buffer adoption process. Most communities require that buffers to fully incorporate all lands within the 100–yr floodplain, and others may extend the buffer to pick up adjacent wetlands, steep slopes or critical habitat areas.

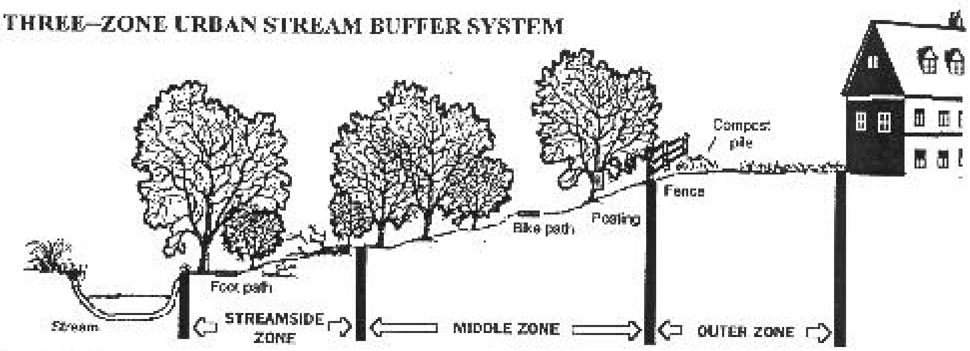
In general, a minimum base width of at least 100 feet is recommended to provide adequate stream protection. In most regions of the country, this requirement translates to a buffer that is perhaps three to five mature trees wide on each side of the channel.

Criteria 2. Three–zone buffer system. Effective urban stream buffers divides the total buffer width into three lateral zones—streamside–middle zone and outer zone. Each zone performs a different function, and has a different width, vegetative target and management scheme, as shown in Figure 26 and described below:

The **streamside zone** protects the physical and ecological integrity of the stream ecosystem. The vegetative target is mature riparian forest that can provide shade, leaf litter, woody debris and erosion protection for the stream. The minimum width is 25 ft from each stream bank—about the distance of one or two mature trees from the streambank.

FIGURE 26: THE THREE–ZONE URBAN STREAM BUFFER SYSTEM

FIGURE 26: THE THREE–ZONE URBAN STREAM BUFFER SYSTEM



CHARACTERISTICS	STREAMSIDE ZONE	MIDDLE ZONE	OUTER ZONE
FUNCTION	Protect the physical integrity of the stream ecosystem	Provide distance between upland development and streamside zone	Prevent encroachment and filter backyard runoff
WIDTH	Min. 25 feet, plus wetlands and critical habitats	50 to 100 feet, depending on stream order, slope, and 100 year floodplain	25 foot minimum setback to structures
VEGETATIVE TARGET	Undisturbed mature forest. Reforest if grass	Managed forest, some clearing allowable	Forest encouraged, but usually turfgrass
ALLOWABLE USES	*Very Restricted* e.g., flood control, utility right of ways, footpaths, etc.	*Restricted* e.g., some recreational uses, some stormwater BMPs, bike paths, tree removal by permit	*Unrestricted* e.g., residential uses including lawn, garden, compost, yard wastes, most stormwater BMPs

Three lateral zones comprise the foundation of an effective urban stream buffer zone. The width, function, management and vegetative target vary by zone.

Land use is highly restricted—limited to stormwater channels, footpaths, and a few utility or roadway crossings.

The **middle zone** extends from the outward boundary of the streamside zone, and varies in width, depending on stream order, the extent of the 100–yr floodplain, adjacent steep slopes and protected wetland areas. Its key functions are to protect key components of the stream and provide further distance between upland development and the stream. The vegetative target for this zone is also mature forest, but some clearing may be allowed for stormwater management, access, and recreational uses. A wider range of activities and uses are allowed within this zone, e.g., recreation, bike paths, and stormwater BMPs. The minimum width of the middle zone is about 50 ft, but it may be expanded based on stream order, slope or the presence of critical habitats.

The **outer zone** is the buffer's buffer, an additional 25 ft setback from the outward edge of the middle zone to the nearest permanent structure. In most instances, it is a residential backyard. The vegetative target for the outer zone is usually turf or lawn, although the property owner is encouraged to plant trees and shrubs, and thus increase the total width of the buffer. Very few uses are restricted in this zone. Indeed, gardening, compost piles, yard wastes, and other common residential activities are promoted within the zone. The only major restrictions are no septic systems cover, permanent structures, or impervious cover.

Criteria 3. Pre–development vegetative target.
The ultimate vegetative target for the streamside and middle zone of most urban stream buffers should be specified as the pre–development riparian plant community— usually mature forest. Notable exceptions include prairie streams of the midwest, or arroyos of the arid West, that may have a grass or shrub cover in the riparian zone. In general, the vegetative target should be based on the natural vegetative community present in the floodplain, as determined from reference riparian zones. Turfgrass is allowed for the outer core of the buffer and is mandatory if the buffer is used as a stormwater treatment system (see Criteria 7).

A vegetative target has several management implications. First, if the streamside zone does not currently meet its vegetative target, it should be managed to ultimately achieve it. For example, a grassy area should be allowed to grow into a forest over time. In some cases, active reforestation may be necessary to speed up the successional process. Second, a vegetative target implies that the buffer will contain mostly native species adapted to the floodplain. Thus, non–native or invasive tree, shrub and vine species should be avoided when revegetating the buffer. Removal of exotic shrubs and vines (e.g., multiflora rose or honey suckle) that are so prevalent along the buffer edge should be encouraged.

Criteria 4. Buffer expansion and contraction.
Many communities require that the minimum width of the buffer be expanded under certain conditions. Thus, while the streamside and outer

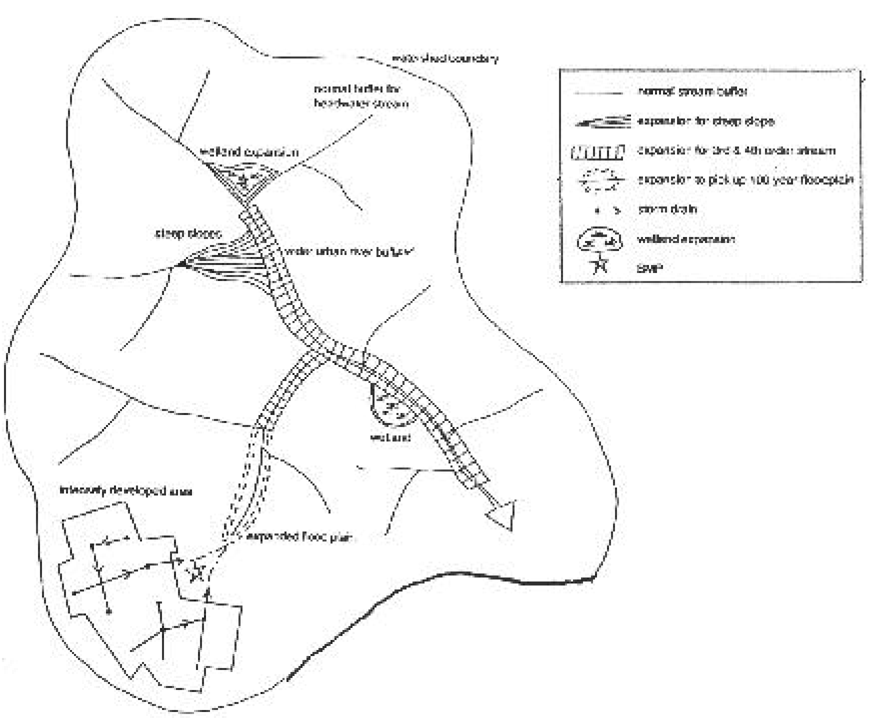
zones of the buffer are fixed, the width of the middle zone may vary. Specifically, the average width of the middle zone can expanded to include:

- the full extent of the 100–yr floodplain
- all undevelopable steep slopes (greater than 25%)
- four additional ft of buffer for each one percent increment of slope above 5%
- any adjacent delineated wetlands or critical habitats

The middle zone also expands to protect streams of higher order or quality in a downstream direction (Fig. 27). For example, the width of the middle zone may increase from 50 ft (for first– and second–order streams) to 75 ft (for third– and fourth–order streams) and as much as 100 ft for fifth– or higher order streams/rivers. The width of the buffer can also be contracted in some circumstances to accommodate unusual or historical development patterns, shallow lots, stream crossings, or stormwater ponds (see Criteria 10).

Criteria 5. Buffer delineation. Three key decisions must be made when delineating the boundaries of a buffer. At what mapping scale will streams be defined? Where does the stream begin and the buffer end? And from what point should the inner edge of the buffer be measured?

FIGURE 27: EXPANSIONS TO THE WIDTH OF URBAN STREAM BUFFERS



The base width of the urban stream buffer may increase to pick up steep slopes, wetlands, and floodplains adjacent to the buffer. In addition, the base width often increases for larger streams and rivers.

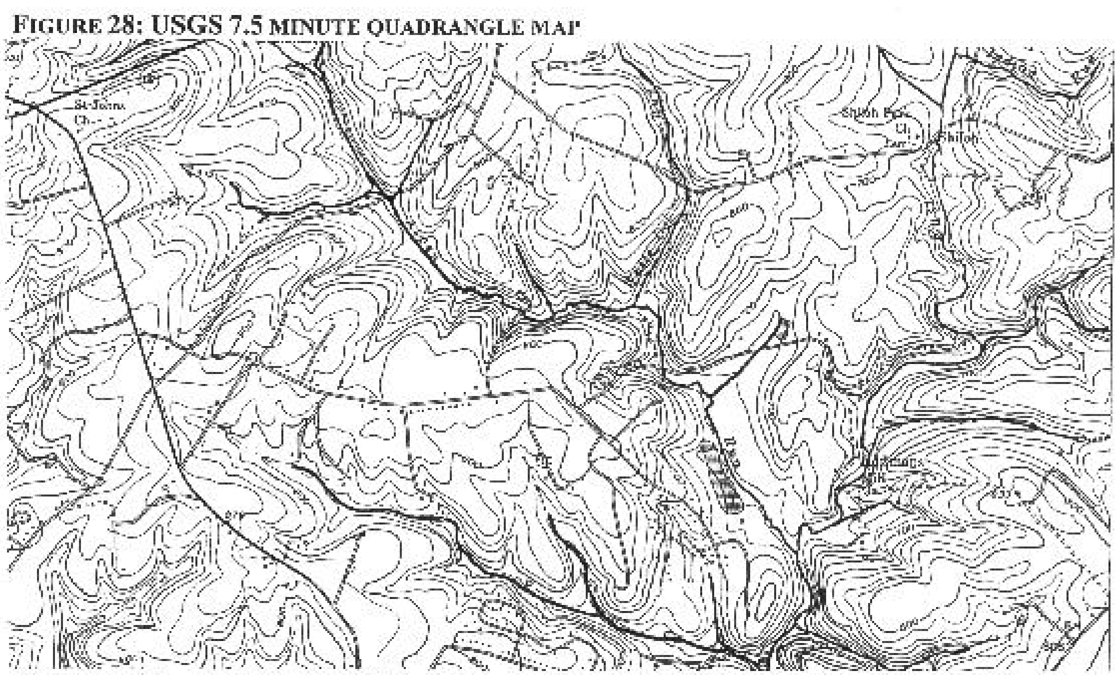
The mapping unit: the traditional mapping scale used to define the stream network are the bluelines present on USGS 7.5 minute quadrangle maps (1 inch=2,000 feet (Fig. 28)). It should be kept in mind that bluelines are only a first approximation for delineating streams, as this scale does not always reveal all first order perennial streams or intermittent channels in the landscape, or precisely mark the transition between the two (MOPS 1993 and Leopold et al. 1964). Consequently, the actual location of the stream channel can only be confirmed in the field.

The *origin of a first order stream* is always a matter of contention. As a practical rule, the origin of the stream can be defined as the point where an intermittent stream forms a distinct channel, as indicated by the presence of an unvegetated streambed and high water marks. Other regions define the origin of a stream as the upper limit of running water during the wettest season of the year.

Problems have frequently been reported in situations where the stream network has been extensively modified by prior agricultural drainage practices, such as ditching.

The *inner edge* of the buffer can be defined from the centerline of small first– or second–order streams. The accuracy of this method is questionable in higher order streams with wider channels. Thus, the inner edge of the buffer is measured from the top of each streambank for third and higher order streams.

FIGURE 28: USGS 7.5 MINUTE QUADRANGLE MAP



Bluelines found on the U.S. Geological Survey's 7.5 minute quad maps provide the initial basis for delineating streams; but final delineation often requires field confirmation.

Criteria 6. Buffer crossings. Two major goals of a stream buffer network are to maintain an unbroken corridor of riparian forest and maintain the upstream and downstream passage of fish in the stream channel. From a practical standpoint, it is not always possible to try to meet both goals everywhere along the stream buffer network. Some provision must be made for linear forms of development that must cross the stream or the buffer (Fig. 29), such as roads, bridges, fairways, underground utilities, enclosed storm drains or outfall channels.

It is still possible to minimize the impact to the continuity of the buffer network and fish passage. Performance criteria should specifically describe the conditions under which the stream or its buffers can be crossed. Some performance criteria could include:

Crossing width: minimum width right of way to allow for maintenance access.

Crossing angle: direct right angles are preferred over oblique crossing angles, since they require less clearing of the buffer.

Crossing frequency: only one road crossing is allowed within each subdivision, and no more than one fairway crossing is allowed for every 1,000 ft of buffer.

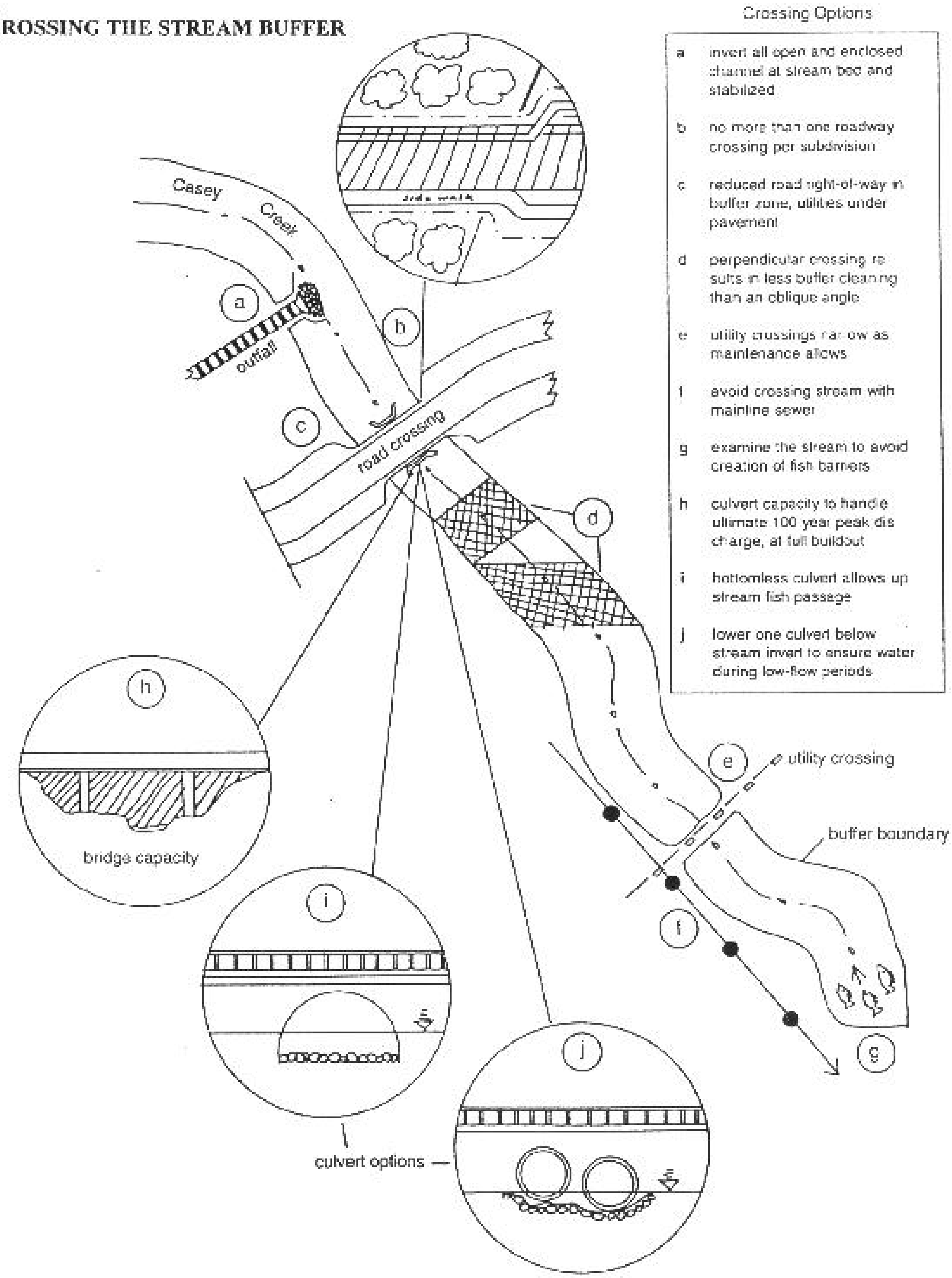
Crossing elevation: all direct outfall channels should discharge at the invert elevation of the stream. Underground utility and pipe crossings should be located at least three feet below the stream invert, so that future channel erosion does not expose them, creating unintentional fish barriers. All roadway crossings and culverts should be capable of passing the ultimate 100–yr flood event. Bridges should be used in lieu of culverts when crossings require a 72 inch or greater diameter pipe. The use of corrugated metal pipe for small stream crossings should be avoided, as these often tend to create fish barriers. The use of slab, arch or box culverts are much better alternatives. Where possible, the culvert should be “bottomless” to ensure passage of water during dry weather periods (i.e., the natural channel bottom should not be hardened or otherwise encased).

Criteria 7. Stormwater runoff. Buffers can be an important component of the stormwater treatment system at a development site. They cannot, however, treat all the stormwater runoff generated within a watershed (generally, a buffer system can only treat runoff from less than 10% of the contributing watershed to the stream). Therefore, some kind of structural BMP must be installed to treat the quantity and quality and stormwater runoff from the remaining 90% of the watershed. More often than not, the most desirable location for stormwater practices is within or adjacent to the stream buffer. The following guidance is recommended for integrating stormwater BMPs into the buffer:

a. <u>The use of buffers for stormwater treatment.</u> The outer and middle zone of the stream buffer may be used as a combination grass/forest filter strip under very limited circumstances (Fig. 30). For example:

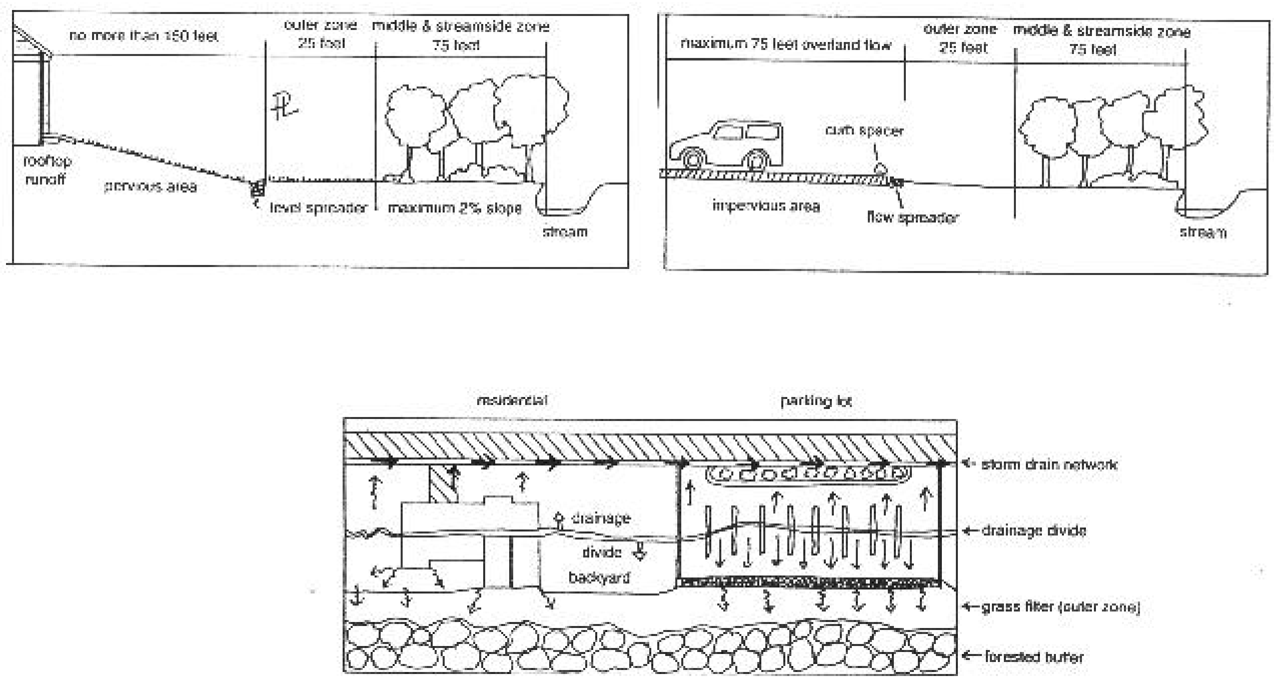
The buffer cannot treat more than 75 ft of

FIGURE 29: CROSSING THE STREAM BUFFER



Two major goals of a stream buffer are to maintain an unbroken riparian corridor and to allow for fish passage. Therefore, the conditions under which the buffer can be crossed should be clearly laid out.

FIGURE 30: DESIGN CRITERIA FOR USING A STREAM BUFFER FOR STORMWATER TREATMENT



Under some conditions, the stream buffer can be used to treat the quality of stormwater runoff from adjacent pervious and impervious areas.

overland flow from impervious areas and 150 ft of pervious areas (backyards or rooftop runoff discharged to the backyard). The designer should compute the maximum runoff velocity for both the six–month and two–year storm designs from each contributing overland flow path, based on the slope, soil, and vegetative cover present. If the computation indicates that velocities will be erosive under either condition (greater than 3 fps for 6–mo storm, 5 fps for 2–yr storm), the allowable length of contributing flow should be reduced.

When the buffer receives flow directly from an impervious area, the designer should include curb cuts or spacers so that runoff can be spread evenly over the filter strip. The filter strip should be located 3 to 6 inches below the pavement surface to prevent sediment deposits from blocking inflow to the filter strip. A narrow stone layer at the pavement's edge often works well to protect the strip from eroding.

The stream buffer can only be accepted as a stormwater filtering system if basic maintenance can be assured, such as routine mowing of the grass filter, and annual scraping and removal of sediments that build up at the edge of the impervious area and the grass filter. The existence of an enforceable maintenance agreement that allows for public maintenance inspection is also helpful.

b. Locating stormwater ponds and wetlands in the buffer. A particularly difficult management issue involves where stormwater ponds and wetlands be located in relation to the buffer? Should they be located inside or outside of the buffer? If they are allowed within the buffer, where exactly should they be put? Some of the possible options are outlined in Table 30 and Figure 31.

A number of good arguments can be made for locating ponds and wetlands within the buffer or on the stream itself. Constructing ponds on or near the stream, for example, affords treatment of the greatest possible drainage area treated at a topographic point that makes construction easier and cheaper. Second, ponds and wetlands require the dry weather flow of a stream to maintain water levels and prevent nuisance conditions. Lastly, ponds and wetlands add a greater diversity of habitat types and structure, and can add to the total buffer width in some cases.

On the other hand, locating a pond or wetland in the buffer can create environmental problems, including the localized clearing of trees, the sacrifice of stream channels above the BMP, the creation of a barrier to fish migration, modification of existing wetlands, and stream warming. Locating ponds and wetlands in buffers will always be a balancing act. Given the effectiveness of stormwater ponds and wetlands in removing pollutants, it is generally not advisable to completely prohibit their use within the buffer. It does make sense, however, to choose pond and wetland sites carefully. In this respect, it is useful to consider possible performance criteria that restrict the use of ponds or wetlands to:

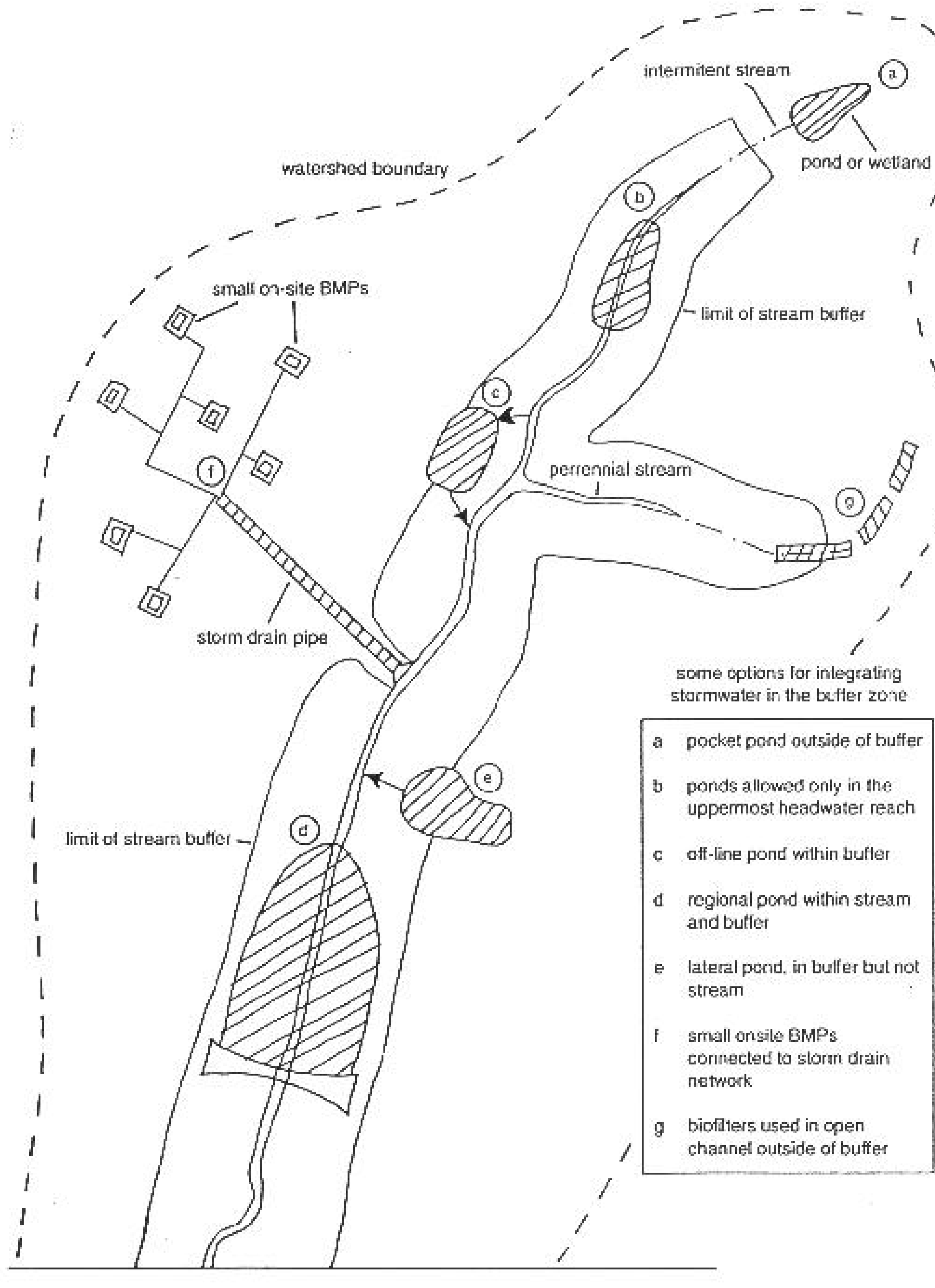
- a maximum contributing area (e.g., 100 acres), or
- the first 500 feet of perennial stream channel, or
- clearing of the streamside buffer zone only for the outflow channel (if the pond is discharging from the middle zone into the stream)

TABLE 30: OPTIONS FOR LOCATING STORMWATER BMPS WITHIN THE STREAM BUFFER ZONE

Location of the Stormwater BMP	Preferred Stormwater BMP to Use
1. outside of the buffer system	infiltration, sand filters, pocket ponds and wetlands
2. upper end of the buffer zone	Stormwater pond or wetland
3. in the outer core	filters, infiltration
4. in the middle core	off–line pond or wetland
5. in the conveyance system	biofilters, grassed swales
6. the outer core and middle zone	vegetated buffer treatment system

The preferred BMP option depends on where stormwater treatment is allowed within the stream buffer.

FIGURE 31: OPTIONS FOR LOCATING STORMWATER PRACTICES IN THE BUFFER



A range of options are available for locating stormwater practices within the stream buffer. Ponds or wetlands can be located only on (a) intermittent streams, (b) in the upper 300 feet of perennial streams, (c) off–line, (d) regional ponds or (e) laterally within the buffer. Alternatively, other BMPs can be located outside of the buffer; although their outfalls may still require a buffer crossing.

- off–line locations within the middle or outer zone of the buffer, or
- use ponds only to manage stormwater quantity within the buffer.

Criteria 8. Buffers during plan review and construction. The limits and uses of stream buffer systems should be well defined during each stage of the development process—from initial plan review through construction. The following steps are helpful during the planning stage:

- require that the buffer be delineated on preliminary and final concept plans
- verify the stream delineation in the field
- check that buffer expansions are computed and mapped properly
- check suitability of buffer for stormwater treatment
- ensure that the other BMPs are properly integrated in the buffer
- examine any buffer crossings for problems

Stream buffers are vulnerable to disturbance during construction. Steps to prevent encroachment during this stage include:

- mark buffer limits on all plans used during construction (i.e., clearing and grading plans, and erosion and sediment control plans)
- conduct a preconstruction stakeout of buffers to define limit of disturbance
- mark the limit of disturbance with silt or snow fence barriers, and signs to prevent the entry of construction equipment and stockpiling
- familiarize contractors with the limit of disturbance during a preconstruction walk–through.

Criteria 9. Buffer education and enforcement. The future integrity of a buffer system requires a strong education and enforcement program. Two primary goals of a buffer are to make the buffer "visible" to the community, and to encourage greater buffer awareness and stewardship among adjacent residents. Several simple steps that can accomplish these goals include:

- mark the buffer boundaries with permanent signs that describe allowable uses
- educate buffer owners about the benefits and uses of the buffer with pamphlets, streamwalks and meetings with homeowners associations
- ensure that new owners are fully informed about buffer limits/uses when property is sold or transferred.
- engage residents in a buffer stewardship program that includes reforestation and backyard "bufferscaping" programs
- conduct annual bufferwalks to check on encroachment

The underlying theme of education is that most encroachment problems reflect ignorance rather than contempt for the buffer system. The awareness and education measures are intended to increase the recognition of the buffer within the community. Not all residents, however, will respond to this effort, and some kind of limited enforcement program may be necessary (Schueler 1994). This usually involves a series of correction notices and site visits, with civil fines used as a last resort if compliance is not forthcoming. Some buffer ordinances have a further enforcement option, whereby the full cost of buffer restoration is charged as a property lien (Schueler 1994). A fair and full appeals process should accompany any such enforcement action.

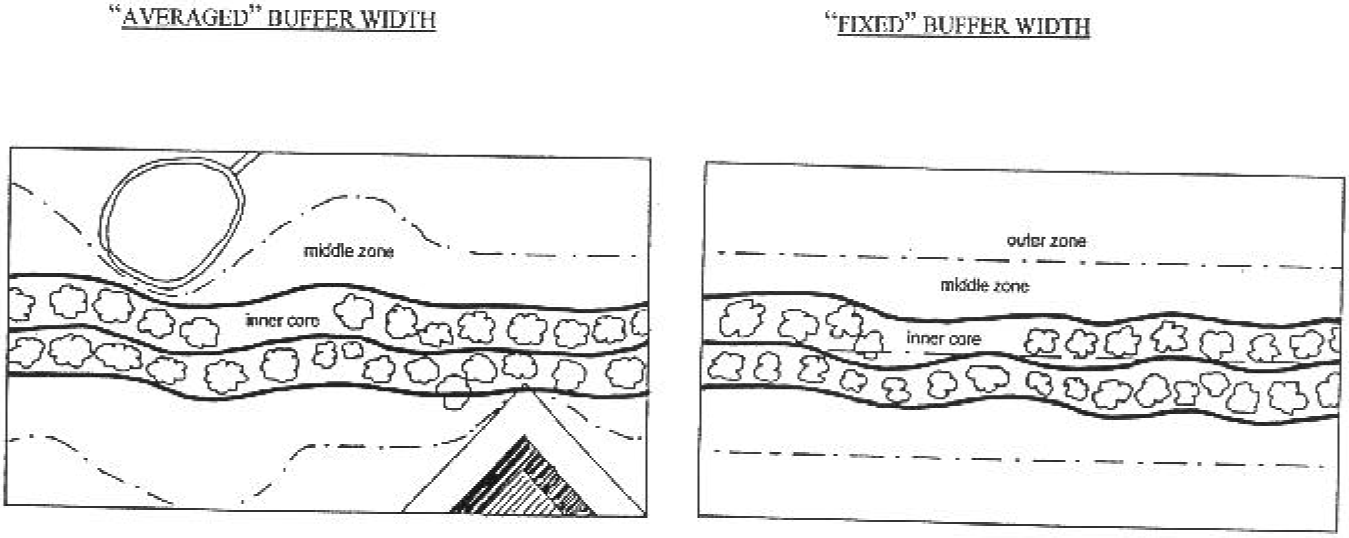
Criteria 10. Buffer flexibility. In most regions of the country, a hundred foot buffer will take about 5% of the total land area in any given watershed out of production. While this constitutes a relatively modest land reserve at the watershed scale, it can be a significant hardship for a landowner whose property is adjacent to a stream. Many communities are legitimately concerned that stream buffer requirements could represent an uncompensated taking of private property. These concerns can be eliminated if a community incorporates several simple measures to ensure fairness and flexibility when administering its buffer program. As a general rule, the intent of the buffer program is to modify the *location* of development in relation to the stream but not its overall *intensity*. Some flexible measures in the buffer ordinance include:

Maintaining buffers in private ownership. Buffer ordinances that retain property in private ownership generally are considered by the courts to avoid the takings issue, as buffers provide compelling public safety, welfare and the environmental benefits to the community that justify partial restrictions on land use. Most buffer programs meet the "rough proportionality" test recently advanced by the Supreme Court for local land use regulation (Hornbach 1993). Indeed stream buffers are generally perceived to have a neutral or *positive* impact on adjacent property value. The key point is that the reservation of the buffer cannot take away all economically beneficial use for the property. Four techniques–buffer averaging, density compensation, variances and conservation easements—can ensure that property owners are fully inoculated from this rare occurrence.

Buffer averaging. In this scheme, a community provides some flexibility in the width of the buffer. The basic concept is to permit the buffer to become narrower at some points along the stream (e.g., to allow for an existing structure or to recover a lost lot), as long as the *average* width of the buffer meets the minimum requirement (Fig. 32). In general, buffer narrowing is limited, such that the streamside zone is not disturbed, and no new structures are allowed within the 100–yr floodplain (if this is a greater distance).

Density compensation. This scheme grants a developer a credit for additional density elsewhere on the site, in compensation for developable land that has been lost due to the buffer requirement. Developable land is defined as the portion of buffer area remaining after the 100–yr floodplain, wetland, and steep slope areas have been subtracted. Credits are granted when more than 5% of developable land is consumed, using the formula shown in Table 31. The density credit is accommodated at the development site by allowing greater flexibility in setbacks, frontage distances or

FIGURE 32: STREAM BUFFER DELINEATION: AVERAGING IN THE MIDDLE ZONE



Under buffer averaging, the width of the buffer can vary from point to point, as long as the average width in the parcel meets the local criteria. The streamside zone, however, should not be encroached on.

TABLE 31: DENSITY COMPENSATION FORMULA FOR STREAM BUFFERS

Percent of Site Lost to Buffers	Density Credit (*)
1 to 10 %	1.0
11 to 20%	1.1
21 to 30%	1.2
31 to 40%	1.3
41 to 50%	1.4
51 to 60%	1.5
61 to 70%	1.6
71 to 80%	1.7
81 to 90%	1.8
91 to 99%	1.9

* Additional dwelling units allowed over based density (1.0)

** Density credit may be transferred to a different parcel

This density compensation formula, loosely adapted from Burns (1992), is based on the premise that the purpose of a buffer is to maintain distance from the stream, and not to reduce allowable density.

minimum lot sizes to squeeze in "lost lots." Cluster development also allows the developer to recover lots that are taken out of production due to buffers and other requirements (cf Chapter 4).

Variances. The buffer ordinance should have provisions that enable a existing property owner to be granted a variance or waiver, if the owner can demonstrate severe economic hardship or unique circumstances make it impossible to meet some or all of the buffer requirements. The owner should also have access to an administrative appeals process should a request for a variance be denied.

Conservation Easements. Landowners should be afforded the option of protecting their portion of the buffer in a perpetual conservation easement. The easement conditions the use of the buffer, and can be donated to a land trust as a charitable contribution that can reduce an owner's income tax burden. Alternatively, an easement can be donated to a local government, in exchange for a reduction or elimination of property tax on the parcel.

Resources Needed for Implementation

To implement a stream buffer program, a community will need to adopt an ordinance, develop technical criteria, and invest in additional staff resources and training.

The buffer ordinance should contain the ten performance criteria described previously. A suggested checklist for the ordinance can be found in Table 32.

The real costs of instituting a buffer program for local government involve the extra staff and training time to conduct plan reviews, provide technical assistance, field delineation, construction and ongoing buffer education programs. Seventy percent of the governments surveyed by Heraty (1993) indicated that their staff expended no more than 10% more time to review buffers. In most cases, these economies were achieved by combining plan review and inspection functions with existing environmental design requirements. However, it should be noted that many of these programs did not contain all of the performance criteria recommended in this chapter, so that the stated costs are probably on the low side (i.e., many respondents did not devote staff resources to delineate stream boundaries in the field).

The adoption of a buffer program also requires an investment in training for the plan reviewer and the consultant alike. Manuals, workshops, seminars and direct technical assistance are needed to explain the new requirements to all the players in the land development business.

Lastly, very few local communities yet recognize the critical importance of buffer maintenance to the long–term success of their program. A relatively small staff commitment (often just one individual) to systematically inspect the buffer network before and after construction, and to work with their residents to increase and maintain awareness about buffers, can be an excellent investment in local stream protection.

TABLE 32: CHECKLIST FOR ADOPTING A STREAM BUFFER ORDINANCE

Providing Authority for the Stream Buffer
- G Is it structured to comprehensively address all stream protection elements?
- G Does it contain clear and simple performance standards?
- G Does it utilize practical operating definitions and mapping units?
- G Does the it support and unify the existing development review process?

Setting an Appropriate Threshold for Development
- G Does it clearly define the activities that constitute "development?"
- G Does it set forth reasonable exemptions?
- G Does it contain provisions for waivers (and waiver fees) if a stream buffers are not feasible at the site?

Providing Funding Support for Program Administration
- G Does it authorize the collection of plan review/inspection and other fees?
- G Are initial operating funds committed to support review staff?

Reducing Potential for Future Conflict in Plan Review
- G Does it require delineation of all resource protection areas before concept plans are considered?
- G Does it specify the nature of submittal requirements for plan review?
- G Does it contain a defined time–table for plan review action?
- G Does it allow for buffer averaging and/or density compensation?

Ensuring Compliance
- G Does it contain a rapid and unified enforcement process?
- G Does it require the posting of performance bonds?

Avoiding Legal Landmines
- G Does it contain a fair and timely appeals procedure?
- G Does it address grandfathering of recorded plats?
- G Does it make allowances for special or unusual developments?
- G Does it contain a severability clause?
- G Are variances included?
- G Are technical criteria adequately supported and referenced?

Many communities focus on technical criteria when crafting a stream buffer ordinance. As this checklist indicates, successful buffer programs also emphasize institutional, review and enforcement aspects (adapted from Schueler 1994)

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